Analysis to Support Louisiana's Flood Risk and Resilience Program and Application to the National Disaster Resilience Competition

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January 12, 2016

Preface

The United States Department of Housing and Urban Development is making nearly $1 billion of funds available to states that have recently experienced a presidentially declared major disaster through the Natural Disaster Resilience Competition. Successful state applicants will be able to use these funds for recovery and other efforts to improve their resilience to future disasters. On October 27, 2015, the State of Louisiana submitted to this competition an application which proposes to use provided funds to elevate residential structures in Plaquemines, Lafourche, and Terrebonne parishes to reduce the risk of future flooding from storm surge.

The State of Louisiana asked RAND to help develop this proposal by performing a quantitative analysis of the baseline flood risks and different allocations of funds for mitigation across the three parishes. RAND used a flood risk model and data developed for Louisiana's 2017 Coastal Master Plan to perform and analysis and create a decision support tool to help the State evaluate flood risks and the effects of different nonstructural mitigation projects.

Questions or comments about this report and accompanying decision support tool should be sent to the project leaders, David Groves (groves@rand.org) and Kenneth Kuhn (kkuhn@rand.org).

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Summary

Despite improvements in levees surrounding New Orleans completed after Hurricane Katrina, much of coastal Louisiana continues to face significant risk from storm surge flooding. For example, Hurricane Isaac in 2012 caused widespread flooding, leading to $2.39 billion of damage and 34 lives lost. Other tropical cyclones have had, and will continue to have, similar significant impacts on the Louisiana coast. Louisiana's 2012 Coastal Master Plan estimated that without action to protect and restore Louisiana's coast, damages from coast wide storm surge flooding are estimated to increase from an average of $2.2 billion annually (in 2012) to between an average of $7.2 billion annually and $20.9 billion (in 2061) in current dollars, depending on future assumptions.

Nonstructural measures, such as elevating residential properties above potential flood waters mitigates risk by reducing damages caused by flood events. The United States Department of Housing and Urban Development is making funds available to areas that have been recently struck by natural disasters via the Natural Disaster Resilience Competition. The funds will enable selected communities to improve their resilience. The State of Louisiana is proposing to use the available funds to elevate residential structures in Plaquemines, Lafourche, and Terrebonne parishes.

To support the State of Louisiana's (the State's) application to the HUD National Disaster Resilience Competition (NDRC), this study builds on the on-going 2017 Coastal Master Plan analysis to define and evaluate a project to elevate residential structures in three target regions of coastal Louisiana: Plaquemines, Lafourche, and Terrebonne parishes.

This study proposed and analyzed different allocations of nonstructural funding to communities within the three project areas. For each project variant, the analysis defined in which block group mitigation should occur, how many structures to elevate, and the estimated cost of that mitigation. Different project variants considered were defined in terms of: the size / budget level of the project, the elevation standard applied when elevating residential structures, whether or not areas where flood depths are expected to increase above the level where elevation is a cost-effective option are eligible for project work, and how project work in different areas was prioritized. For example, one project specifies expenditures of $75 million in Lafouche Parish, $75 million in Terrebonne Parish, and $100 million in Plaquemines Parish. Structures would be elevated to a height 2 feet above the local Base Flood Elevation and all areas were eligible for project work (no filter applied) in this example project. Project work would be carried out in the areas with the highest flood depths first and work continued until the (parish-specific) project budget is spent in this example project. Flood depths are here being used as a proxy for flood risk, with spending being prioritized in areas that are at most risk. Elevation would not be a feasible option and is not recommended in areas where flood depths are

exceptionally high (details provided within report). The report describes an innovative method for prioritizing areas for project work based on a composite criterion including components for flood depths, socioeconomic data, and estimates of cost-effectiveness.

RAND also developed a decision support tool that allows users to see the areas where structures are elevated once a project definition has been specified. The user can visualize data describing conditions in the project area and outside of the project area. The user can explore projected project costs and counts of the structures mitigated in different geographic areas. The tool allows the user to compare the benefits and costs of different project variants, using standard measures such as Net Present Value and Cost-Benefit Ratio. The user can also compare alternative projects to the project that the State of Louisiana will propose.

The results show that there are relatively few structures in Lafourche Parish for which elevation is a cost-effective flood risk mitigation strategy. This result is due to (1) the presence of the Larose to Golden Meadow structural flood protection system that leads to low risk for much of the populated area in this parish under current flood depths; and (2) high projected flood depths in other areas that rule out elevating structures. Many of the areas where the State proposes elevating structures have populations that are more than 50 percent low to moderate income, particularly in Terrebonne and Plaquemines parishes. The State's recommended project provides higher benefits than costs in each of Terrebonne, Lafourche, and Plaquemines parishes. The benefits and costs are lowest in Lafourche Parish since, for the reasons mentioned above, relatively few structures are elevated here. Nonstructural work in Terrebonne and Plaquemines parishes offers more promise.

The methodology applied in this study allowed Louisiana to examine how the composition of flood risk mitigation projects changes in accordance with different policy-maker preferences for providing mitigation in low to moderate income areas or regions that have experienced repetitive losses in the past. The approach could be used to develop nonstructural projects in other communities. Flood risk modeling tools, such as CLARA, are increasingly available and can be used to evaluate risks over a wide range of flood events. Planning organizations can then augment risk data with other metrics, such as LMI or repetitive loss data to identify the communities where nonstructural investments should be prioritized. The Planning Tool can serve as an example of a useful, flexible means of supporting the development of a comprehensive plan for coastal flood risk mitigation.

The analysis presented here provides Louisiana with an innovative method and new insights related to nonstructural risk reduction planning, but it is not without limitations. It relies on a single projection of future conditions in one plausible scenario drawn from the 2012 Coastal Master Plan analysis, for example. Alternate plausible scenarios might yield different results. Conversely, some data inputs are treated as static although conditions will certainly change in the future. Examples include the use of historical data on repetitive loss properties and low to moderate income populations.

Acknowledgements

Abbreviations

ADCIRC	Advanced Circulation model
BCR	Benefit Cost Ratio
BFE	Base Flood Elevation
CLARA	Coastal Louisiana Risk Assessment model
CPRA	Coastal Protection and Restoration Authority
EAD	Expected Annual Damage
FWOA	Future Without Action
HUD	Department of Housing and Urban Development
LMI	Low to moderate income
NDRC	National Disaster Resilience Competition
NPV	Net Present Value
RL	Repetitive Loss

Introduction

Despite improvements in levees surrounding New Orleans completed after Hurricane Katrina, much of coastal Louisiana continues to face significant risk from storm surge flooding. For example, Hurricane Isaac in 2012 caused widespread flooding, leading to $2.39 billion of damage and 34 lives lost. Other tropical cyclones have had, and will continue to have, similar significant impacts on the Louisiana coast.

Louisiana's 2012 Coastal Master Plan (Coastal Protection and Restoration Authority (CPRA), 2012)[1] estimated that without action to protect and restore Louisiana's coast, damages from coast wide storm surge flooding are estimated to increase from an average of $2.4 billion annually (in 2010) to an average of $23.4 billion annually (in 2060). As part of the analysis supporting the 2012 Coastal Master Plan, the Master Plan Delivery Team developed and evaluated "nonstructural projects" for 56 regions. Each of these projects specified for each region the extent to which residential structures would need to be elevated, the extent of flood-proofing residential and commercial structures, and the acquisition of at-risk properties. These projects are labeled nonstructural to differentiate them from projects involving the construction of levees, floodwalls, locks, and other structures. The 2012 Coastal Master Plan included about $10 billion of investments in nonstructural projects that when combined with coastal restoration and structural protection projects, would significantly decrease flood risk.

For the 2017 Coastal Master Plan, the previous analysis conducted for the 2012 Plan is being refined for the purpose of identifying the most cost-effective nonstructural risk mitigation projects at a higher geographic resolution. The Coastal Louisiana Risk Assessment (CLARA) model used for the 2012 Coastal Master Plan effort was based on evaluation of conditions at 35,556 Census block centroids. The model that will be used for 2017 Coastal Master Plan development will be based on conditions at 90,373 geographic locations in Louisiana. The higher resolution model will enable CPRA to better target its investments in nonstructural projects across the coast.

To support the State of Louisiana's (the State's) application to the HUD National Disaster Resilience Competition (NDRC), this study extends the on-going 2017 Coastal Master Plan analysis to define and evaluate a project to elevate residential structures in three target regions of coastal Louisiana: Plaquemines, Lafourche, and Terrebonne parishes. Figure 1 shows the areas within these parishes that are eligible for project work. Eligible areas are those that are populated, are found within HUD NDRC Phase 1 designated environmental degradation census tracts, and were previously shown in the 2012 Coastal Master Plan to face significant risk due to coastal flooding.

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[1] http://coastal.la.gov/a-common-vision/2012-coastal-master-plan/

Figure 1. Target areas considered for nonstructural investments
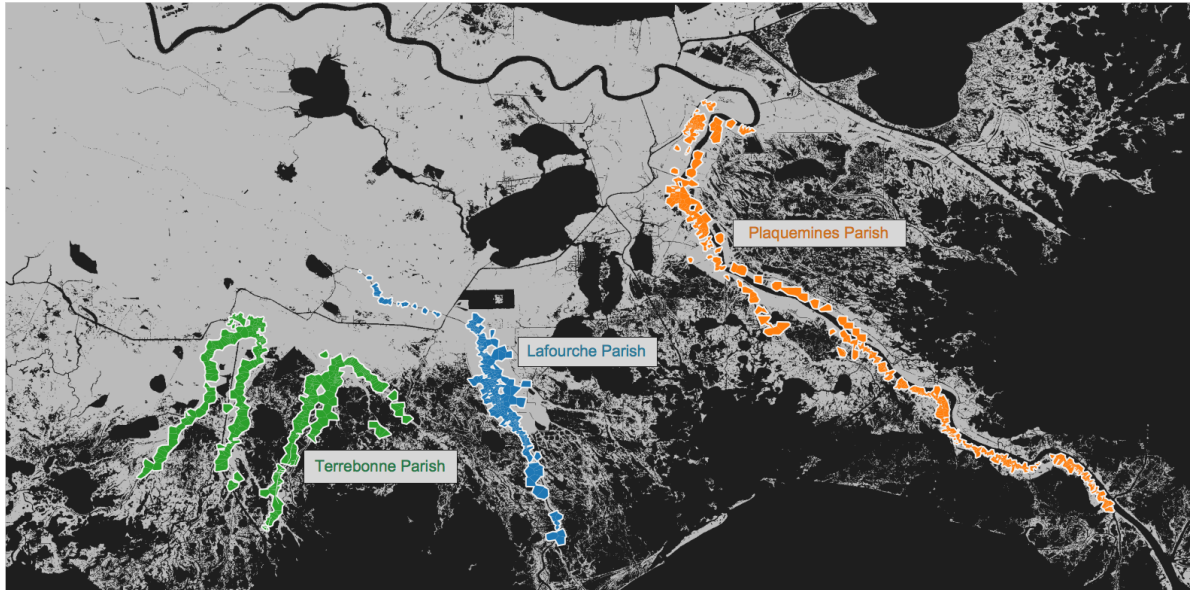
Several project variants, alternative definitions of a project that elevates structures in the areas shown in Figure 1, were evaluated in this study. The project variants are defined by the locations where structures are to be elevated and the associated numbers of structures to be elevated.

Methods

This section describes the flood risk model that supported project definition and analysis before precisely describing how project variants were defined.

Modeling Flood Risk

This study evaluates flood risk in the target regions with and without nonstructural projects using the Coastal Louisiana Risk Assessment (CLARA) flood risk model (Fischbach *et al.*, 2012; Johnson *et al.*, 2013). CLARA is used to estimate flood depths and economic damages. A version of the CLARA model that has been updated to support Louisiana's 2017 Coastal Master Plan analysis was used in this study (Fischbach *et al.*, 2015).

Figure 2 provides a high-level overview of the CLARA model. CLARA takes as input storm surge and wave height estimates from a dynamically coupled version of the Advanced Circulation (ADCIRC) and Simulating Waves Nearshore (SWAN) model for a large sample of hypothetical storms. CLARA also requires as input the location, elevation, and composition of hurricane protection systems, land elevations, and the historical record of storm events. Estimates of land elevation at a 30-meter resolution were derived from the U.S. Geological Survey's Digital Elevation Model of the area. This data source was updated and validated in 2011. Data regarding the location, elevation, and composition of hurricane protection systems were obtained from the State of Louisiana and the U.S. Army Corps of Engineers. More details are provided in Fischbach et al. 2012.

Given the necessary input data, the CLARA model estimates flood depths across the coast based on land elevations and the estimated performance of hurricane protection systems. CLARA considers areas that are fully enclosed by protection systems and areas where overtopping of protection systems occurs. CLARA further considers the probability that these systems will fail based on estimates of the fragility of the engineered systems. To ensure spatial continuity, CLARA's interior drainage sub-module equalizes flood depths among adjacent areas.

CLARA estimates a cumulative distribution function for surge and wave elevations at each of several thousand grid points and extracts the flood elevations corresponding to exceedances at anywhere from the 5-year return period (20 percent annual chance) to the 2,000-year return period (0.05 percent annual chance). The estimates are based on the large sample of 446 hypothetical storms simulated in the ADCIRC/SWAN model.

Figure 2. CLARA model structure
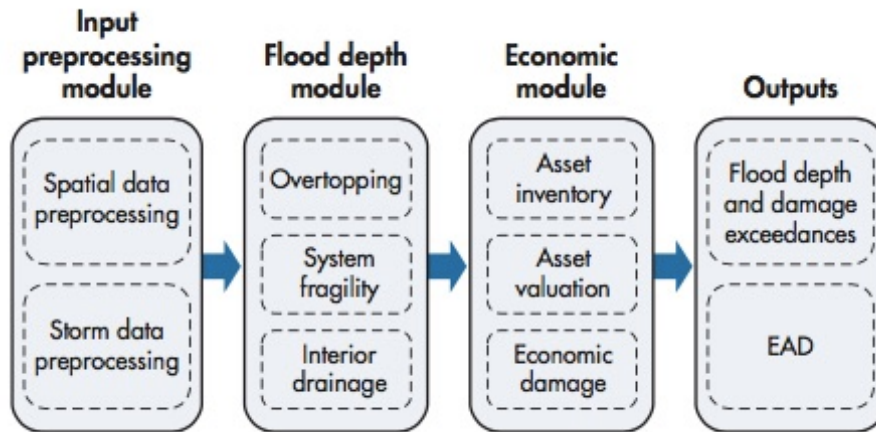
The next step of CLARA's calculations is to estimate the economic damage to structures and infrastructure at each return period. The damage sustained by a building is a function of flood depth and flood depth/damage curves. Value and damage calculations follow standard methodologies used by the FEMA Hazus-MH model.[2] Asset inventory data are drawn from the most current, high-quality data sources available for the study regions (see Fischbach et al., 2015 for more details).

Lastly, the CLARA model calculates Expected Annual Damage (EAD). EAD is the amount of damage that would occur in each year, on average, from the coastal storm surge and wave events ranging from the 5-year to 2,000-year flood. CLARA estimates EAD at each of several thousand locations along the coast (called 'grid points' in CLARA). It can also aggregate the results to more commonly used geographic areas such as U.S. Census block groups (Figure 3).

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[2] https://www.fema.gov/hazus

Figure 3. Census block groups for each target area
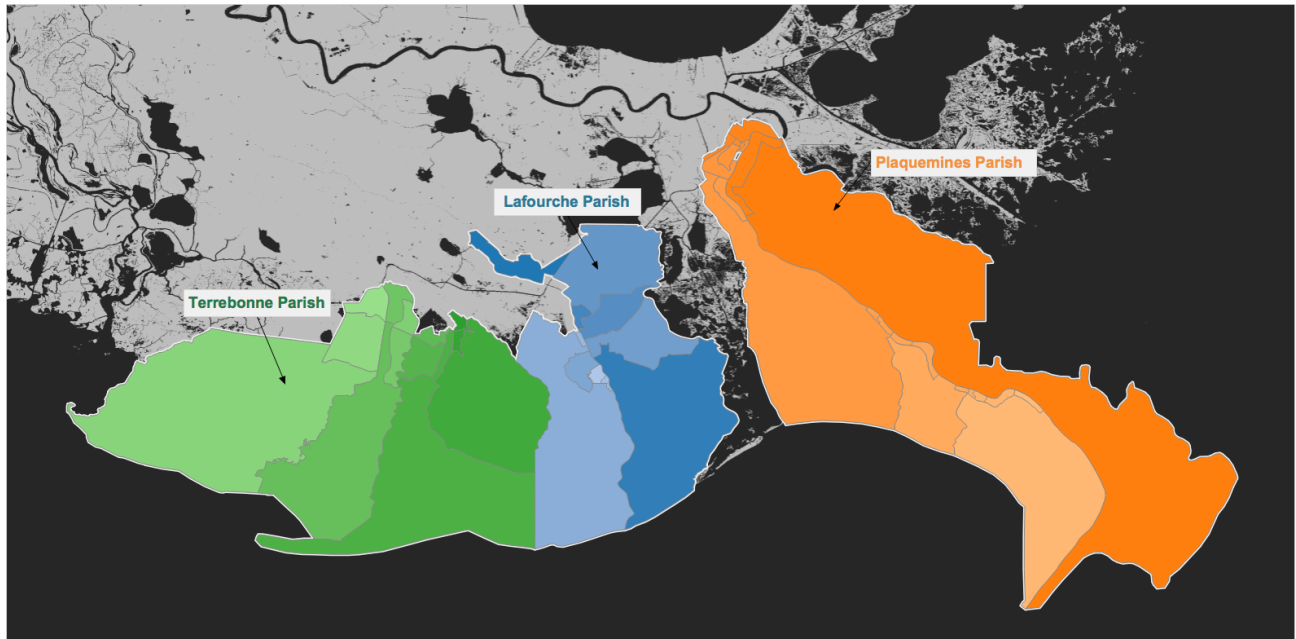
Formulation of Nonstructural Risk Reduction Projects

Nonstructural projects are designed to reduce flood risk by decreasing the damage sustained by a structure during a flood. Elevation of residential properties is one class of nonstructural projects. In CLARA, elevating structures is modeled by adjusting the flood depth/damage curves by the height of the elevation. This analysis developed a set of nonstructural project variants using different specifications, as described below.

1) Size of project

To constrain the options considered to the practicalities of available funding, the State defined a range of budgets for each parish (Figure 4). The Low budget ranges between \$50M and \$75M per parish, whereas the High budget ranges between \$100M and \$125M per parish[3] Figure 4 shows the budgets considered, by parish.

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[3] This study also examined how many structures would be elevated if cost were not a constraint. This assumption is not used to guide recommended levels of mitigation for the HUD application.

Figure 4. Budgets for nonstructural alternative formulation
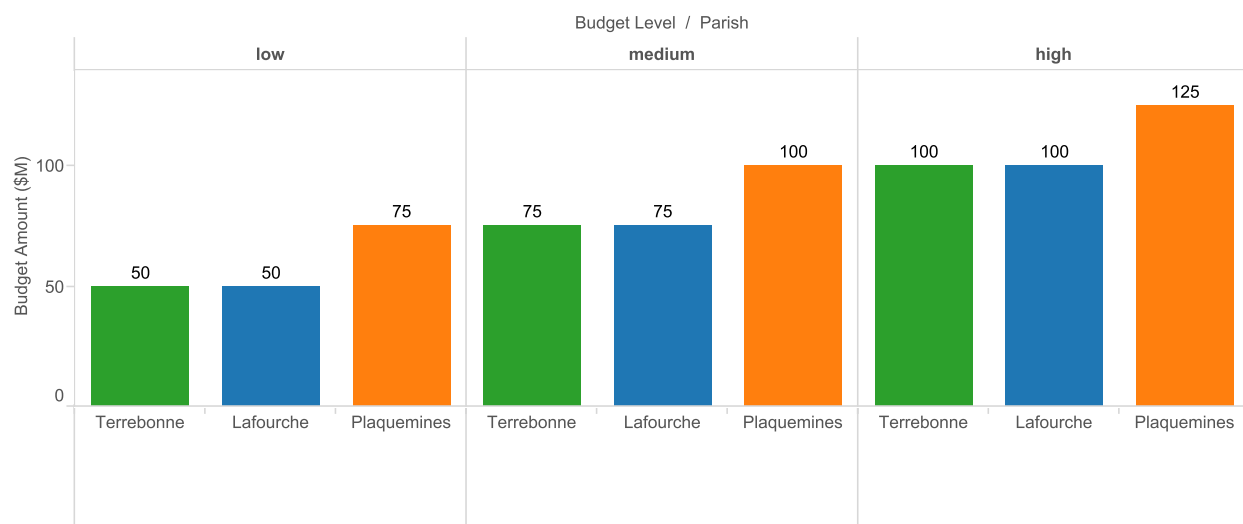
2) Elevation standard

The modified CLARA model estimates the number of structures that could be cost-effectively elevated at each of its grid points. CLARA considers elevation standards of 1 and 2 feet above a base flood elevation (BFE) level. For this analysis, the State proposed the use of current 100-year flood depths as the BFE, along with 2 feet of freeboard.[4] Consistent with the 2012 Coastal Master Plan analysis, CLARA includes an assumption that 80 percent of structures that would benefit from elevation are elevated (i.e., an 80 participation rate). As in most projects like this, funds would be made available to homeowners who want to elevate their homes, but elevation would not be mandatory. Also consistent with the 2012 Coastal Master Plan analysis, any structures that would need to be elevated higher than 14 feet above ground level would be deemed infeasible and thus excluded from the project.[5]

For a specific project, CLARA also estimates the cost of the elevation of the structures. Costs, in constant 2015 US dollars, are estimated using a schedule of cost per square foot by elevation height found in the State of Louisiana's Flood Risk and Resilience Program Framework document.[6] The cost of elevating a structure 3 to 7 feet is $82.50 per square foot. The cost of elevating a structure 7 to 10 feet is $86.25 per square foot. The cost of elevating a structure 10 to 14 feet is $103.75 per square foot. These cost estimates include allowances for design and engineering work, surveying and soil sampling, permitting and title search,

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[4] Freeboard is the safety factor added to flood depths when determining how high to elevate structures in order to account for uncertainty and to lower risk.

[5] In the 2017 Coastal Master Plan analysis, the project would specify acquisition for these structures.

[6] Note that these broad assumptions are designed to help CPRA identify areas where nonstructural mitigation would be effective in reducing risk. The specific estimates of number of structures or height of structures at any specific location would need to be refined prior to a project's implementation.

inspections, physical lifting and lowering of the structure, demolition and disposal of an old foundation, construction of a new foundation, construction of stairs, landings, and railings, utilities work, basic landscape restoration, and reasonable living expenses for temporary relocation. The estimates are similar to those used in the 2012 Coastal Master Plan work and empirical results observed by the State of Louisiana in Terrebonne Parish.

3) Filtering on future flood depths

As described in Step 2, this analysis specifies that the BFE be set to the current 100-year flood depth. To better understand how changing flood depths over time would affect nonstructural project formulation, alternative project variants were developed that excluded structures in areas where the 100-year flood depths in 50 years were higher than 12 feet. These flood depths imply a future increase in risk or need to elevate structures more than 14 feet (12 feet of depth plus 2 feet of freeboard).

The current 100-year flood depth data are used to set elevation targets both in project variants where filtering on future flood depths is and is not applied.

4) Area (grid point) selection criteria

The State considered a variety of different vulnerability metrics for use in deciding which grid points would be included in each nonstructural project. Each metric is intended to capture different perspectives on the areas in which investment should be prioritized. The State considered four vulnerability metrics:

- Current 100-year flood depths
- Future (year 50) 100-year flood depths
- Percentage of low to moderate income (LMI) households (at present)
- Number of repetitive loss and severe repetitive loss (RL) properties

The CLARA model estimates the 100-year flood depth today and 50 years into the future, assuming no new structural flood protection systems are built, directly for each grid point. Estimates of the percentage LMI households and number of repetitive loss and severe repetitive loss properties by grid point were derived from data from the Department of Housing and Urban Development (HUD) and FEMA, respectively. Figure 5 shows the geographic patterns of current 100-year flood depths (upper) and percent of low to moderate income properties (lower). Note that each metric has a different spatial pattern. As a result, projects that seek to mitigate in areas with the highest 100-year flood depth could recommend elevating different properties than projects that seek to emphasize mitigation in locations with high percentages of low to moderate income households. In other words, the choice of vulnerability metric will determine the property selection for the project.

Figure 5. Year 1 flood depths (upper) and low to moderate income values (lower) for each grid point
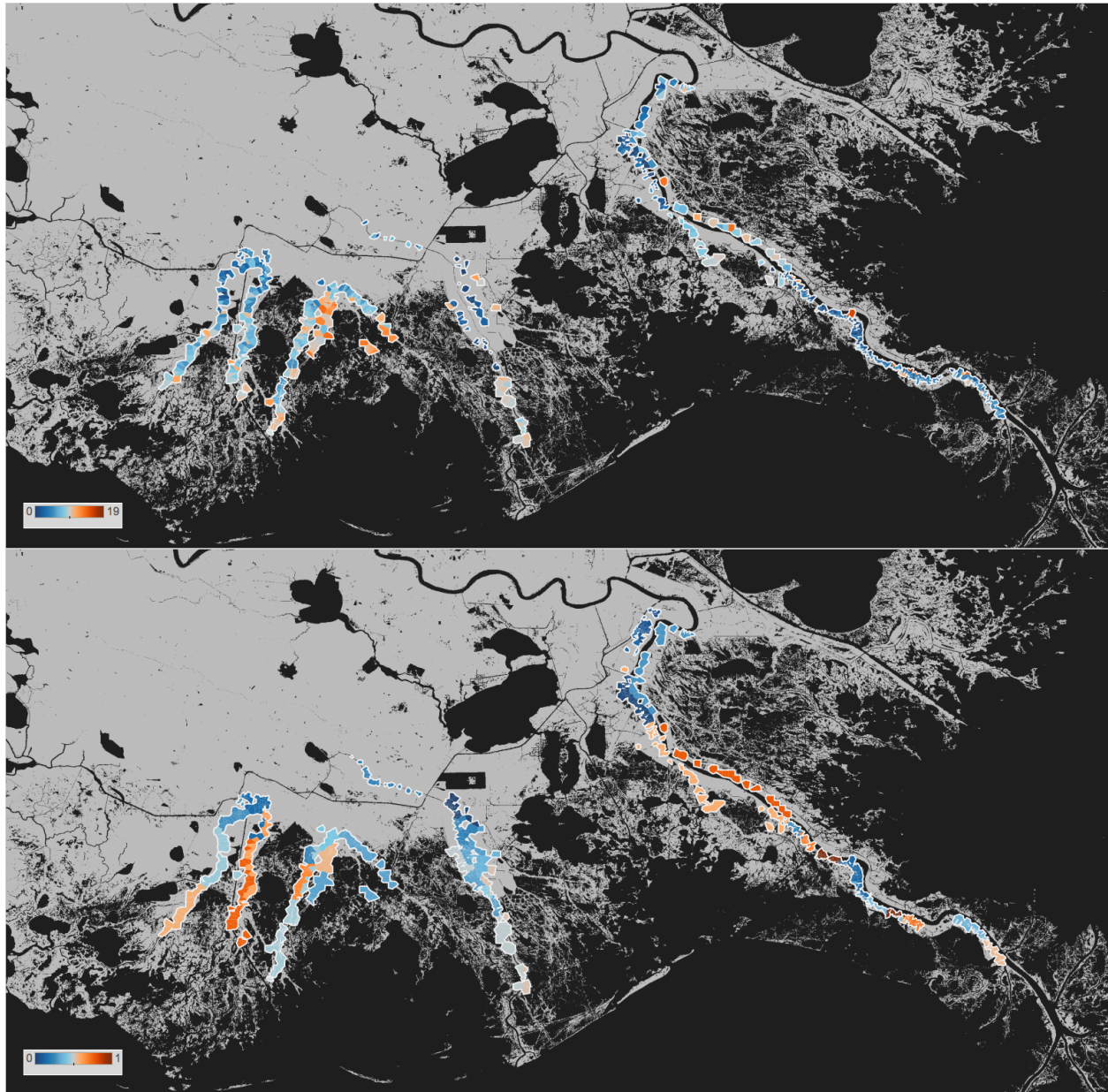
Five different criteria were employed to define alternatives, using the four vulnerability metrics plus cost effectiveness:

1. Current 100-year flood depths only
2. Future (year 50) 100-year flood depths only
3. Percentage of LMI properties only
4. Number of RL properties only

5. Combined criterion (based on LMI, current flood depth, and cost effectiveness metrics)

The first four criteria considered each of the four vulnerability metrics separately. For example, for the 100-year flood depths in year 1 only, CLARA selects grid points in the order of highest to lowest 100-year flood depths until the budget for each parish is exhausted.[7]

The analysis also considered a fifth composite criterion. This composite criterion is calculated by combining estimates of the cost-effectiveness of the potential elevation activities at each grid point with the percentage of the population in the area that is LMI, and the year 1 flood depth. Cost effectiveness is defined here as the reduction in EAD, under year 1 flood depths, divided by the total undiscounted cost of a project.

As these components of the composite criterion are quantified using different units—risk reduction per investment cost, percentage of households, and feet of flooding depth—they must be projected onto a common scale in order to combine them. The following equation is used to scale each component of the metric:[8]

$$\text{Scaled value of a component} =$$
$$[\text{Score at a grid point} - \text{Mean score across all grid points in eligible areas}] /$$
$$\text{Standard deviation across all grid points in eligible areas}$$

The composite criterion then sums the three individual rescaled components. As with the other criteria, CLARA then selects the grid points starting with the highest composite score until the budget is exhausted.

In total, the analysis formulated and evaluated 80 different project variants for the three parishes—the full factorial combination of the following variables:
- 4 budgets (including no budget limit)
- 2 elevation standards
- 2 options for filtering on future flood depths
- 5 area / grid point selection criteria

This analysis characterizes each project variant by reporting the number of structures to be elevated and the cost of doing so by Census block group and type of structure—single family residential, small multi-family, and manufactured homes.

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[7] Recall that elevation is not recommended for structures that would need to be elevated higher than 14 feet.

[8] Note that the scaled variables are dimensionless and do not necessarily reflect any assumption regarding the distributions of the variables of interest.

Evaluation of Nonstructural Project Benefits and Costs

Each nonstructural project is evaluated in terms of its risk reduction benefit, mitigation cost, net present value (NPV), and benefit-cost ratio (BCR).

The risk reduction benefit is defined as the difference in EAD without a project versus EAD with a project. This yields an estimate of average annual net benefit across coastal flood events ranging from the 5-year to the 2,000-year event, weighted by the event's likelihood. The benefits are assumed to begin in year 1 and continue for 50 years, and are discounted and summed to yield a net present benefit estimate. A discount rate of 7 percent is applied when discounting future benefits. This corresponds to the base case discount rate from the Office of Management and Budget's Circular A-94, and is the discount rate recommended by the Department of Housing and Urban Development. These statistics are calculated for each project variant, both at the parish and block group levels.

A project's cost of mitigation is simply a sum of the cost of elevating the structures that the project recommends elevating. It is assumed that all construction costs would be incurred immediately (in year 0). NPV is defined as risk reduction benefit minus cost, and the BCR is calculated as net present benefit divided by cost. Benefits and costs are calculated for the elevation of structures only—single-family homes, small multi-family structures, and manufactured homes.

NPV and BCR are calculated using two different sets of assumptions to better illustrate the value of projecting future changes in flood depths and damage. One approach uses current condition flood depths, and uses a constant dollar estimate of damage reduction to estimate benefits. This is consistent with standard benefit-cost practice using only a current snapshot of risk. However, the 2012 Coastal Master Plan analysis clearly showed that flood risk in coastal Louisiana will increase over time due to sea level rise, coastal subsidence, and other environmental drivers. The new Federal Flood Risk Management Standard, finalized in January 2015, gives federal agencies the flexibility to develop flood risk standards using "…best-available, actionable data and methods that integrate current and future changes in flooding based on science" (Exec. Order No. 13690, 2015). Thus the alternate approach included here is consistent with this new guidance, and combines both current and future estimates of flood depths and damage in order to estimate how flood damage –and corresponding damage reduction benefits—could increase over time.

Specifically, the alternate approach linearly interpolates benefits between current (year 1) and future (year 50) damage estimates for each of the intervening years, as a first-order approximation of how damage and nonstructural damage reduction benefits could increase over time. These interpolated values are then discounted to present value as described above. The rate of increase could be higher or lower than the linearly interpolated rate over this time period, but

without available information about damage in the intervening years, there is no basis for selecting any rate other than the linearly interpolated rate. Interpolation was applied only to estimates of economic damages and not to flood depth data. However, as economic damages are a function of flood depths, the results describe a situation where flood depths increase slowly and roughly linearly over time.

For the regions considered in this analysis, benefits are generally estimated to be higher in the future due to higher flood depths and asset values. Therefore, the first approach is considerably more conservative and significantly under represents benefits. The State recommends using the second (alternate) approach as appropriate for benefit-cost estimates, subject to further elaboration during 2017 Coastal Master Plan analysis.

Decision Support

A decision support tool was developed to compare the attributes and outcomes of different project variants. The "Planning Tool" was based on a similar tool developed to support the 2012 Coastal Master Plan (Groves and Sharon, 2013; Groves *et al.*, 2012). It is implemented in the Tableau visualization platform[9] and provides a set of interactive graphics driven directly from a database of results from the CLARA model.

The Planning Tool serves two primary purposes. First, it was used to guide the analysis by providing a convenient and user-friendly way to review interim results. The figures shown in this report are static reproductions of some of the visualizations. Second, the Planning Tool provides easy access to the results by others: a link to results produced by the Planning Tool will accompany the State's application to HUD. These results are available online at the following web address:

https://public.tableau.com/views/LA-HUD-NS_Analysis/ANALYSIS

The Planning Tool includes the following visualizations:
- Map of the target areas
- Vulnerability metrics across the target areas
- Steps and options for formulating projects
- Included locations for each project (by grid point)
- Counts of structures mitigated and costs (by Census block group)
- Outcomes for each project in terms of EAD reduction, cost, NPV, and BCR
- Comparisons of structures mitigated and costs between projects

Specific results from the Planning Tool are shown in the Results section below.

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[9] More information on Tableau can be found on the developer's website—www.tableausoftware.com.

Findings

The State used the CLARA-based analysis and Planning Tool to review key results for the full range of project variants described above although only the State only proposes a single project. To help guide the State's proposal to HUD, this analysis focused on variants using the following specifications:

- A range of budgets for each parish, varying from $50M to $125M
- An elevation standard of 2 feet above BFE, based on current 100-year flood depths
- Use of year 1 flood depths
- The composite criterion for area selection

The next subsection provides the details of the State's proposed project specification, chosen from among the project variants. The following subsection compares the recommended specification to different variants to better understand the key tradeoffs that the State considered when defining its proposed nonstructural project.

Proposed Nonstructural Project

Mitigation and Cost

The Planning Tool defined the proposed nonstructural project based on application of the range of budget levels and criterion for area selection defined above, and also identified alternate projects based on different specifications. Table 1 shows the number of structures elevated and associated costs for the three budget levels considered for the State's proposed nonstructural project.

Table 1. Structures mitigated and cost by block group

Parish	Low budget		Medium budget		High budget	
	Structures	Costs	Structures	Costs	Structures	Costs
Lafourche	47	$7.1M	47	$7.1M	47	$7.1M
Plaquemines	495	$75.0M	667	$100.0M	838	$125.0M
Terrebonne	321	$50.0M	483	$75.0M	638	$100.0M

Table 1 shows that the number of structures increases from low to high budgets from about 500 to 840 in Plaquemines Parish and from about 320 to 640 in Terrebonne Parish. In all cases for these two parishes, the Planning Tool selection process makes use of the full budgets available. However, in Lafourche Parish, the proposed project includes the elevation of only 47

structures at a cost of around $7,000,000, regardless of the budget level. This result is due to (1) the presence of the Larose to Golden Meadow structural flood protection system that leads to low risk for much of the populated area in this parish under current flood depths; and (2) high projected flood depths in other areas that rule out elevating structures. Note that this result is also a byproduct of the use of current flood depths when calculating risk reduction and the cost effectiveness metric. Flooding within the Larose to Golden Meadow system is projected to be more frequent and severe in future years, so if future flood depths were used as the basis for cost effectiveness calculations, residential elevations in this area might show greater potential.

The spatial distribution of areas mitigated across the budget range varies considerably in Plaquemines and Terrebonne parishes (Figure 6). At the higher budget level, more areas are included, particularly in lower Plaquemines Parish.

Figure 6. Distribution of mitigation for low budget (top) and high budget (bottom) and associated year 1 flood depths for the proposed project
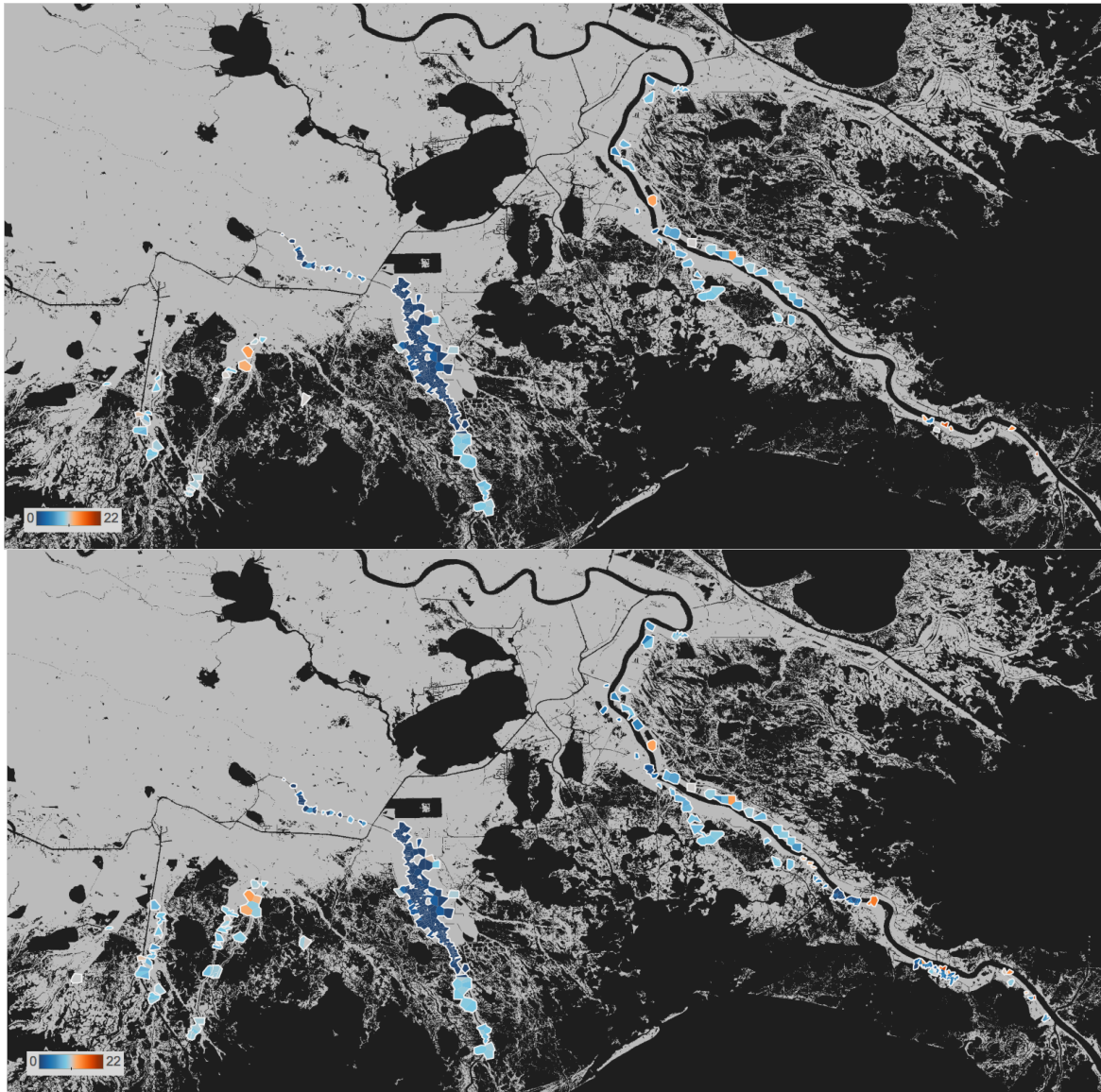
The State's proposed nonstructural program seeks to provide cost effective mitigation to households that are subject to high flood depths and that have high percentages of low to moderate income populations. Figure 7 shows the average percentage of low to moderate income households for areas included in the high budget proposed project. Note that many areas included in the project have populations that are more than 50 percent low to moderate income, particularly in Terrebonne and Plaquemines parishes.
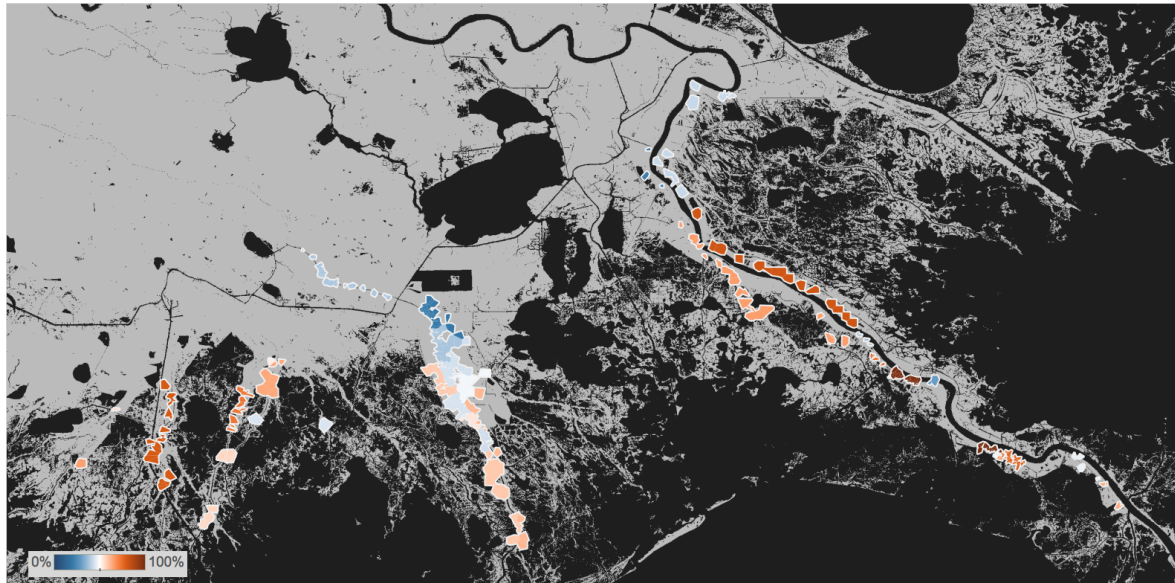
Even under the high budget project, however, not all areas in Terrebonne and Plaquemines Parishes are included in the proposed nonstructural project. Figure 8 shows the areas that are excluded from the proposed nonstructural program. In both parishes, these excluded areas have generally low flood risk and/or high LMI percentages. Note that the components of the composite criterion can be compensatory, e.g., a very low score with regards to current flood depths can mask a high LMI score and produce a low combined criterion value.

Figure 8. Populated areas not included in proposed nonstructural program (high budget): colors showing associated current flood depths (top) and average low to moderate income levels (bottom)
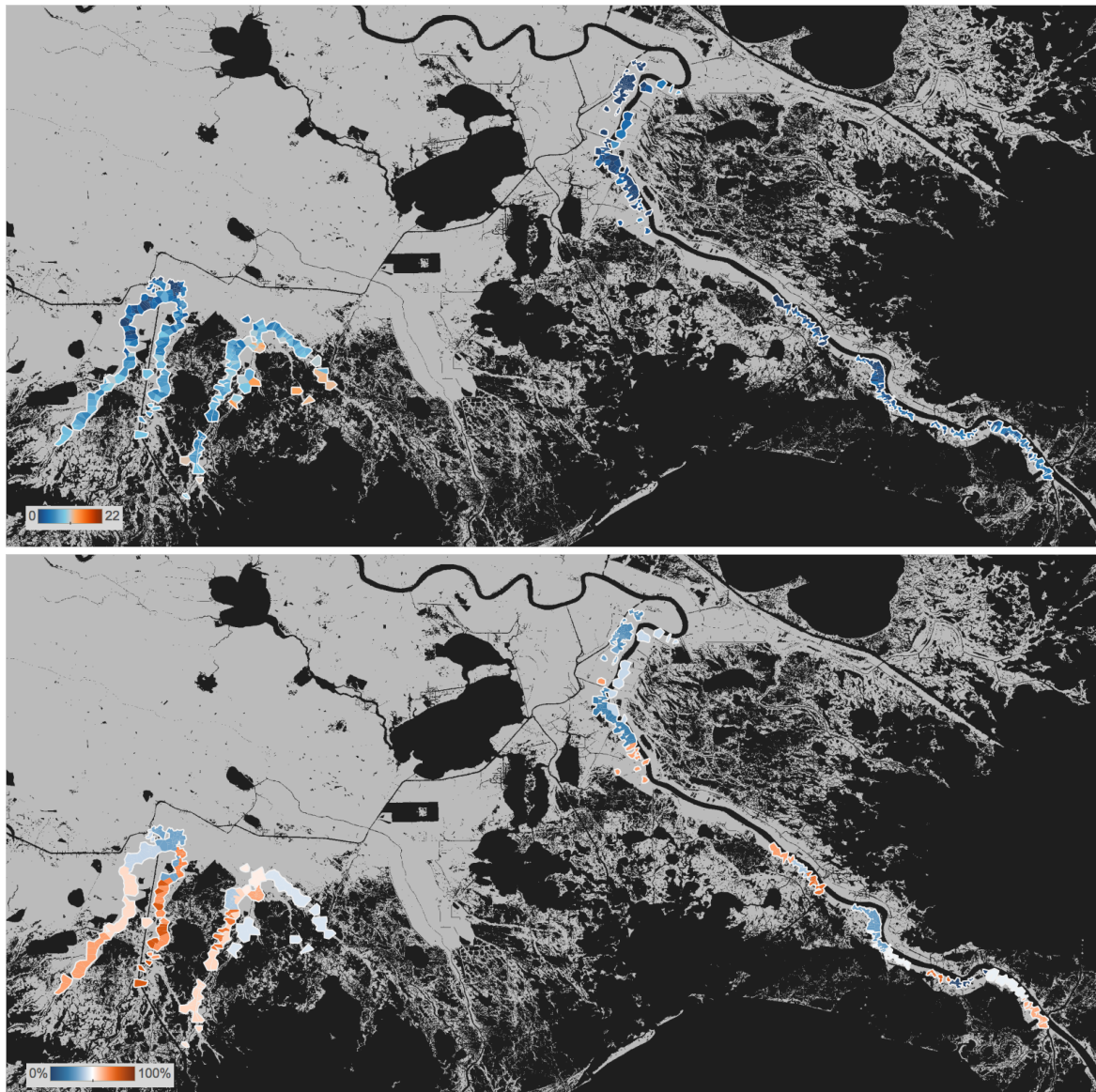
To provide a more concise summary of locations of elevations for the proposed nonstructural project, Figure 9 maps the number of mitigated structures by block group for the high budget proposed project. The majority of the elevations are concentrated in two Census block groups in Plaquemines Parish and three block groups in Terrebonne Parish.

Figure 9. Number of mitigated structures by block group for the high budget proposed project

Baseline Project: **LMI + CE + Yr 1 Depths, BFE +2', high, no filter**
Count of Elevated Structures
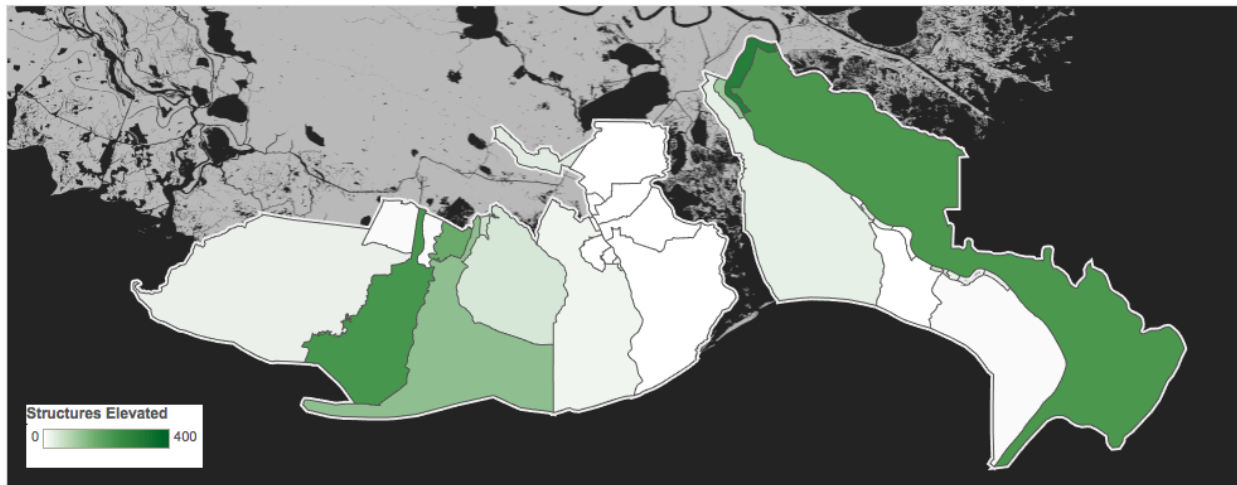
Benefit Cost Analysis for Recommended Project

As part of the selection of the proposed project, the State evaluated the benefits and costs of the different project variants. As shown below, the recommended project provides significantly higher benefits than costs at the Parish level—NPV results are $106M, $2.5M and $23M for Terrebonne, Lafourche, and Plaquemines Parishes, respectively.[10] The corresponding BCRs are 2.4, 1.4, and 1.2. At the higher budget, net benefits increase for Terrebonne Parish to $139M (BCR=2.4) and slightly decline to $11.2M (BCR = 1.1) in Plaquemines Parish. There is uncertainty on both the benefits and costs side but these numbers are certainly encouraging.

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[10] The results presented assume that benefits change over time linearly between the year 1 and year 50 estimates.

Figure 10. Costs, benefits, and net benefits (red line) for the medium budget proposed project
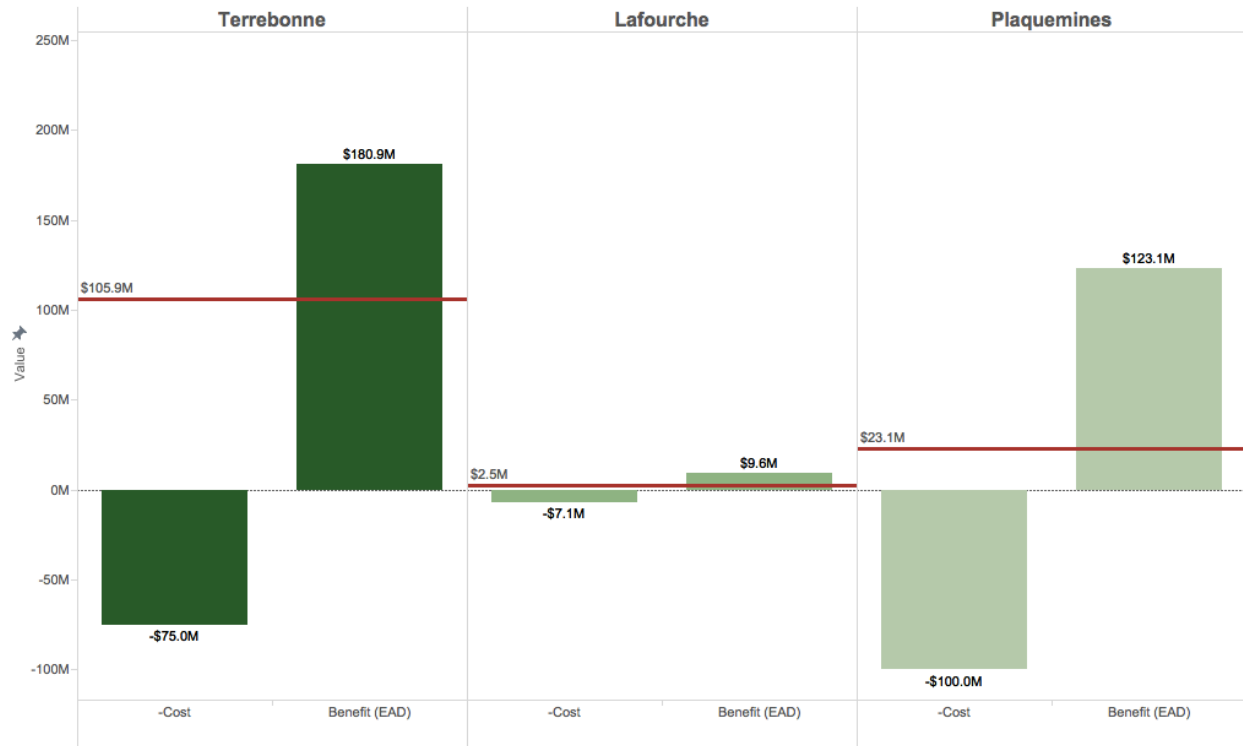
Note: Benefit-cost ratios under the medium budget levels for Terrebonne, Lafourche, and Plaquemines Parishes are: 2.4, 1.4, and 1.2, respectively.

The distribution of net benefits across the block groups is significant—both in terms of total size and sign. As Figure 11 shows, 14 out of 23 (61 percent) block groups show positive net benefits and BCRs greater than 1. As expected, the majority of the net benefits are concentrated in a few block groups. These are areas where there are valuable assets and also where flood depths are high enough to produce sizable damages but low enough to make elevation of structures a feasible and cost-effective option. As noted earlier, the majority of such areas are located in Terrebonne Parish.

Figure 11. Net present value (horizontal axis) and benefit-cost ratio (label and color) for each block group for the medium budget proposed project
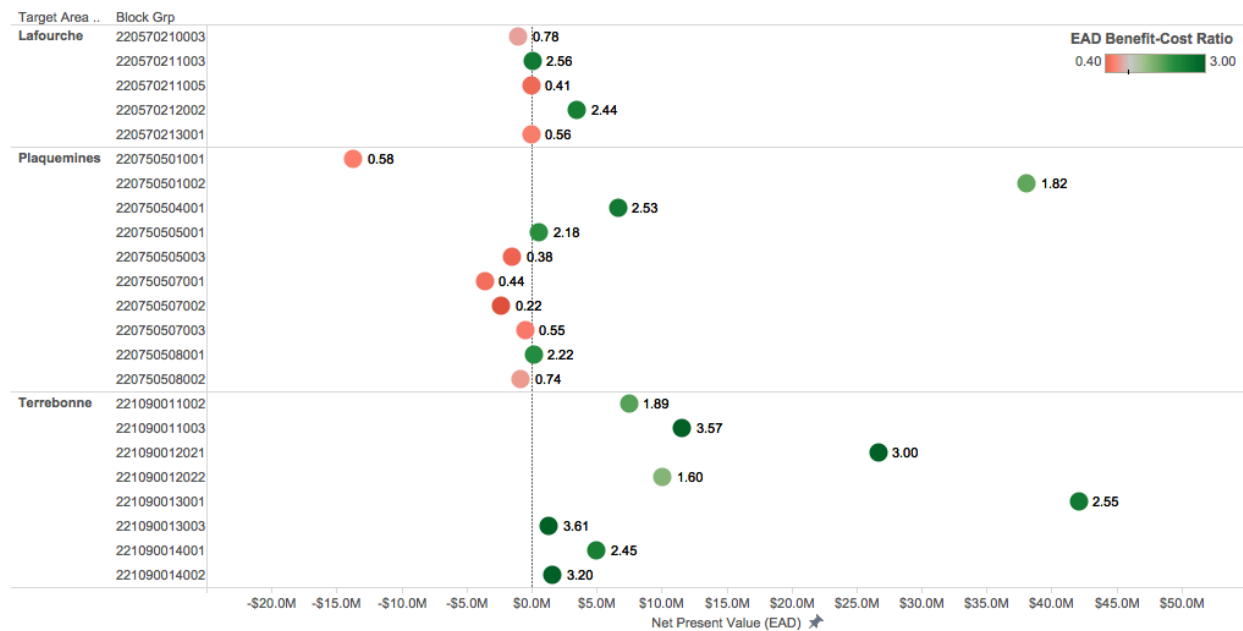
Comparisons to Alternative Project Variants

The State selected the recommended project by considering the full range of project variants. They considered how different specifications led to different mitigation patterns as well as net benefits.

Mitigation and Cost

Figure 12 shows how the number of structures elevated by block group for the proposed nonstructural project compares to that for a project variant. The map on the left shows how many structures are elevated in each block group in the medium budget, proposed project. The map on the right shows the changes in the counts of structures to be elevated when the project definition strategy focuses on the LMI metric alone instead of the combined criterion that combines LMI, cost effectiveness, and flood depth. In Terrebonne Parish, defining the project based on LMI alone focuses project work more heavily on the census block that has the highest proportion of LMI properties. In Plaquemines Parish, defining the project based on LMI alone spreads investment to sparsely populated coastal areas.

Figure 12. Varying the strategy used for project definition, LMI metric
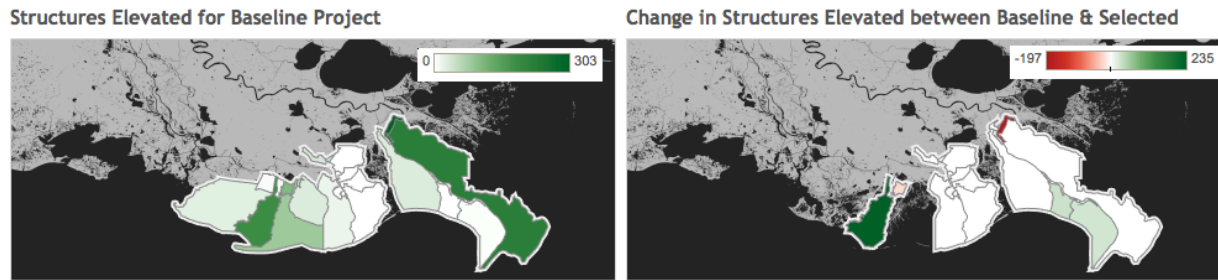
Figure 13 is similar to Figure 12 but compares the proposed project to a variant in which the project definition strategy focuses spending in areas where the 100-year flood depths (under current conditions) are highest. Defining the project based on flood depths alone has the effect of spreading spending more evenly across the block groups in both Terrebonne and Plaquemines parishes.

Figure 13. Varying the strategy used for project definition, flood depth metric
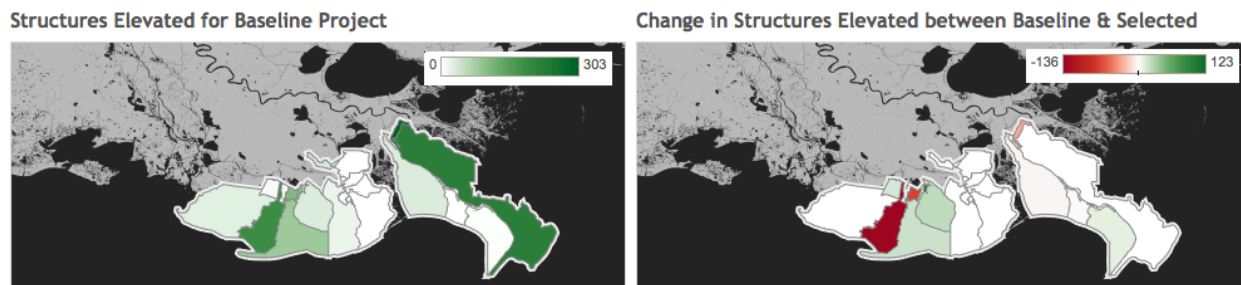
The results in Figure 12 and Figure 13 are similar for Lafourche Parish, since under both cases only 47 structures in the parish are recommended for elevation at a cost of ~$7,000,000. As this total cost is below the budget, the same areas are included in the project regardless of the selection criteria used.

Benefit cost analysis comparisons

The State also compared project variants based on benefit-cost performance. Table 2 lists summary statistics on the benefits and costs for medium budget project variants by parish. The columns in the table are:
- Project cost,
- Benefits in terms of reductions in EAD in Year 1,
- Benefits in terms of reductions in EAD in Year 50,
- Sum of discounted benefits across all 50 years,
- NPV, and
- BCR.

The results are color coded by BCR value—more favorable results are colored a darker shade of green while results reflecting a BCR value less than 1 are colored red.

Table 2: Benefits, costs, NPV, and BCR for middle budget projects using different selection criteria for the three parishes

Benefits and Costs Using EAD

Parish	Project Definition Metric	Cost	Benefit EAD Y1	Benefit EAD Y50	Benefit (EAD)	NPV EAD	BCR EAD
Terrebonne	Year 1 Flood Depths	$75.0M	$11.2M	$16.9M	$176.3M	$101.3M	2.35
	Year 50 Flood Depths	$75.0M	$9.7M	$15.7M	$156.6M	$81.6M	2.09
	LMI Only	$75.0M	$9.0M	$12.8M	$138.4M	$63.4M	1.85
	RL Only	$75.0M	$7.1M	$11.4M	$114.0M	$39.0M	1.52
	LMI + CE + Yr 1 Depths	$75.0M	$11.6M	$17.2M	$180.9M	$105.9M	2.41
Lafourche	Year 1 Flood Depths	$7.1M	$0.6M	$1.1M	$9.6M	$2.5M	1.35
	Year 50 Flood Depths	$7.1M	$0.6M	$1.1M	$9.6M	$2.5M	1.35
	LMI Only	$7.1M	$0.6M	$1.1M	$9.6M	$2.5M	1.35
	RL Only	$7.1M	$0.6M	$1.1M	$9.6M	$2.5M	1.35
	LMI + CE + Yr 1 Depths	$7.1M	$0.6M	$1.1M	$9.6M	$2.5M	1.35
Plaquemines	Year 1 Flood Depths	$100.0M	$7.5M	$12.8M	$123.2M	$23.2M	1.23
	Year 50 Flood Depths	$100.0M	$5.0M	$8.8M	$83.0M	-$17.0M	0.83
	LMI Only	$100.0M	$4.6M	$8.7M	$78.5M	-$21.5M	0.78
	RL Only	$100.0M	$6.8M	$12.4M	$114.9M	$14.9M	1.15
	LMI + CE + Yr 1 Depths	$100.0M	$7.4M	$13.1M	$123.1M	$23.1M	1.23

The proposed project (using the composite criterion), has a positive NPV and a BCR greater than 1 in each of the three target areas considered here and is better than or equal to all other options.[11] For reasons described above, all variants are equivalent in Lafourche Parish. In Plaquemines Parish, projects that are formulated based on year 50 flood depths or on LMI properties only yield negative NPVs and BCRs below 1. This result is consistent across the other budget levels (not shown). The reason for this is that properties with high LMI and 50-year flood depths also tend to be exposed to greater risk and/or have lower total structure and asset values. Projects that prioritize year 50 flood depths or LMI may forgo more cost effective investments in areas that face more moderate risks (where nonstructural solutions perform best) and/or have relatively higher value properties. This tradeoff speaks to the value in the composite criterion used for the proposed project that focuses on LMI, current flood depths, and cost effectiveness.

In Terrebonne Parish, all project variants perform well. Terrebonne Parish is exposed to small and frequent storm events. Nonstructural elevation is particularly cost effective at reducing risks to this type of threat. Since the EAD performance metric captures benefits from (current and future estimates of) surge events ranging from the 5-year to 2,000-year flood, the performance of nonstructural projects in Terrebonne is relatively high.

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[11] In Plaquemines Parish, the variant based on Year 1 Flood Depths has a slightly higher NPV ($23.2M versus $23.1M).

Discussion

This evaluation of nonstructural projects represents an important step forward in policy design and assessment of nonstructural risk mitigation options for coastal regions. The method shown here can support the formulation of large-scale nonstructural projects of the type that are needed to achieve the goals of the Louisiana Coastal Master Plan. Specifically, this method constitutes an advance over standard practice by:

- Using outputs from a detailed flood risk model that incorporates changes in the future coastal landscape and storm hazard, rather than relying on static flood maps;
- Considering a broad range of events—from 5-year to 2,000-year flood events—instead of focusing on a single (i.e., 100-year) or small number of recurrence intervals only; and
- Incorporating additional selection metrics, such as low to moderate income and repetitive loss, when formulating projects.

Importantly, this methodology takes a "deliberation with analysis" approach to providing technical analysis (i.e., flood risk assessments) to support decision making (i.e., developing nonstructural flood mitigation programs) (Groves *et al.*, 2014; National Research Council, 2009). Specifically, this study uses a Planning Tool to explore different possible specifications of nonstructural projects and to consider the tradeoffs in terms of affected areas, cost, and benefits. Further, we have examined how the resulting project compositions change in accordance with different policy-maker preferences for providing mitigation in low to moderate income areas or regions that have experienced repetitive losses in the past.

The analysis presented here provides Louisiana with an innovative method and new insights related to nonstructural risk reduction planning, but it is not without limitations. It relies on a single projection of future conditions in one plausible scenario drawn from the 2012 Coastal Master Plan analysis. Alternate plausible scenarios might yield different results. Conversely, some data inputs are treated as static although conditions will certainly change in the future. Examples include the use of historical data on repetitive loss properties and low to moderate income populations.

This analysis nevertheless provides a step forward and enables the State to define nonstructural projects that complement other risk reduction and coastal restoration projects for the 2017 Coastal Master Plan and improves upon the approach used in 2012 Coastal Master Plan development.

This approach could also be used to develop nonstructural projects in other communities. Flood risk modeling tools, such as CLARA, are increasingly available and can be used to evaluate risks over a wide range of flood events. Planning organizations can then augment risk data with other metrics, such as LMI or repetitive loss data to identify the communities where nonstructural investments should be prioritized. Lastly, the Planning Tool can serve as an

example of a useful, flexible means of supporting the development of a comprehensive plan for coastal flood risk mitigation.

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Appendix – Tabular Results by Block Group

This appendix provides results on the costs and structures mitigated by block group for the proposed nonstructural project. Table 3 shows these results when low budget levels are applied, restricting the spending in each parish. Table 4 shows similar results when medium budget levels are applied and Table 5 shows the results when high budget levels are applied. Lastly, Table 6 shows the results when there is no budget limit applied and all structures are eligible for elevation.

Table 3: Costs and structures mitigated by block group, low budget levels.

Block Group ID	Parish	Cost	Structures Mitigated
220570210003	Lafourche	$4,700,000	32
220570212002	Lafourche	$2,400,000	15
Sum	Lafourche	$7,100,000	47
220750501001	Plaquemines	$33,100,000	220
220750501002	Plaquemines	$34,000,000	216
220750504001	Plaquemines	$4,400,000	27
220750507001	Plaquemines	$4,400,000	31
220750508001	Plaquemines	$100,000	1
Sum	Plaquemines	$75,000,000	495
221090011002	Terrebonne	$2,100,000	14
221090011003	Terrebonne	$3,000,000	18
221090012021	Terrebonne	$10,200,000	63
221090012022	Terrebonne	$10,800,000	68
221090013001	Terrebonne	$22,700,000	150
221090013003	Terrebonne	$500,000	3
221090014002	Terrebonne	$700,000	5
Sum	Terrebonne	$50,000,000	321

Table 4: Costs and structures mitigated by block group, medium budget levels.

Block Group ID	Parish	Cost	Structures Mitigated
220570210003	Lafourche	$4,700,000	32
220570212002	Lafourche	$2,400,000	15
Sum	Lafourche	$7,100,000	47
220750501001	Plaquemines	$33,100,000	220
220750501002	Plaquemines	$46,200,000	302
220750504001	Plaquemines	$4,400,000	27
220750505001	Plaquemines	$400,000	3
220750505003	Plaquemines	$2,400,000	17
220750507001	Plaquemines	$6,400,000	46
220750507002	Plaquemines	$3,000,000	21
220750507003	Plaquemines	$1,000,000	8
220750508001	Plaquemines	$100,000	1
220750508002	Plaquemines	$3,000,000	22
Sum	Plaquemines	$100,000,000	667
221090011002	Terrebonne	$8,400,000	53
221090011003	Terrebonne	$4,500,000	28
221090012021	Terrebonne	$13,400,000	83
221090012022	Terrebonne	$17,000,000	106
221090013001	Terrebonne	$27,000,000	182
221090013003	Terrebonne	$500,000	3
221090014001	Terrebonne	$3,500,000	23
221090014002	Terrebonne	$700,000	5
Sum	Terrebonne	$75,000,000	483

Table 5: Costs and structures mitigated by block group, high budget levels.

Block Group ID	Parish	Cost	Structures Mitigated
220570210003	Lafourche	$4,700,000	32
220570212002	Lafourche	$2,400,000	15
Sum	Lafourche	$7,100,000	47
220750501001	Plaquemines	$33,100,000	220
220750501002	Plaquemines	$46,200,000	302
220750504001	Plaquemines	$4,400,000	27
220750504002	Plaquemines	$15,800,000	106
220750505001	Plaquemines	$400,000	3
220750505002	Plaquemines	$5,000,000	35
220750505003	Plaquemines	$2,400,000	17
220750507001	Plaquemines	$6,400,000	46
220750507002	Plaquemines	$5,200,000	37
220750507003	Plaquemines	$2,600,000	19
220750508001	Plaquemines	$500,000	4
220750508002	Plaquemines	$3,000,000	22
Sum	Plaquemines	$125,000,000	838
221090011001	Terrebonne	$700,000	5
221090011002	Terrebonne	$8,400,000	53
221090011003	Terrebonne	$6,800,000	41
221090012021	Terrebonne	$19,500,000	122
221090012022	Terrebonne	$26,500,000	165
221090013001	Terrebonne	$33,400,000	221
221090013003	Terrebonne	$500,000	3
221090014001	Terrebonne	$3,500,000	23
221090014002	Terrebonne	$700,000	5
Sum	Terrebonne	$100,000,000	638

Table 6: Costs and structures mitigated by block group, no budget limits applied.

Block Group ID	Parish	Cost	Structures Mitigated
220570210003	Lafourche	$4,700,000	32
220570212002	Lafourche	$2,400,000	15
Sum	Lafourche	$7,100,000	47
220750501001	Plaquemines	$33,100,000	220
220750501002	Plaquemines	$46,200,000	302
220750504001	Plaquemines	$4,400,000	27
220750504002	Plaquemines	$42,000,000	280
220750505001	Plaquemines	$3,300,000	23
220750505002	Plaquemines	$5,000,000	35
220750505003	Plaquemines	$2,400,000	17
220750506001	Plaquemines	$1,300,000	9
220750506002	Plaquemines	$4,600,000	32
220750507001	Plaquemines	$6,400,000	46
220750507002	Plaquemines	$5,500,000	39
220750507003	Plaquemines	$2,600,000	19
220750507004	Plaquemines	$8,000,000	58
220750508001	Plaquemines	$4,000,000	30
220750508002	Plaquemines	$16,400,000	120
Sum	Plaquemines	$185,200,000	1,257
221090011001	Terrebonne	$27,500,000	181
221090011002	Terrebonne	$42,000,000	268
221090011003	Terrebonne	$47,000,000	305
221090012021	Terrebonne	$61,600,000	394
221090012022	Terrebonne	$80,000,000	506
221090012023	Terrebonne	$41,000,000	265
221090013001	Terrebonne	$61,500,000	417
221090013002	Terrebonne	$17,500,000	120
221090013003	Terrebonne	$43,500,000	300
221090013004	Terrebonne	$70,500,000	512
221090014001	Terrebonne	$19,000,000	129
221090014002	Terrebonne	$22,000,000	150
221090014003	Terrebonne	$5,500,000	38
Sum	Terrebonne	$538,600,000	3,585